Subsurface Topics

INEEL Subsurface Science Initiative

INEEL Home of Science and Engineering Solutions

Idaho National Engineering and Environmental Laboratory — December 2003 • Volume 4, Issue 3

In This Issue

Initiative Director:
Russel C. Hertzog, Ph.D.
(208) 526-4092
hertr@inel.gov

For general information, or to be added to the mailing list, contact:
Steve Zollinger
(208) 526-9590
gaz@inel.gov

SubsurfaceTopics provides technical partners and interested researchers with information and updates about the INEEL's Subsurface Science Initiative and related research.

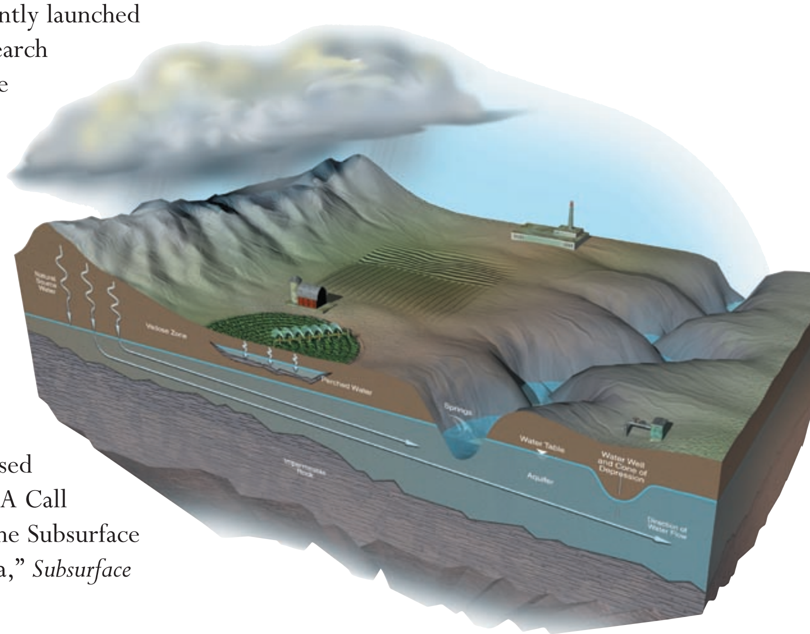
http://subsurface.inel.gov/

Sense of Urgency Prompts Creation of Geoscience Research Consortium

The Consortium for Research on the Earth's Subsurface (CORES), recently launched by the INEEL and LBNL, will be an advocate for geoscience research.

The health and economic welfare of earth's population depends upon a continued supply of clean water, air, and available energy resources. And yet, one-third of the population may lack access to safe and clean resources as early as 2020. The reason for this is clear. Throughout the 20th century, environmental damage has outpaced scientific understanding of earth processes, and our current solutions for mitigating the damage may be insufficient.

In response to the urgent need for solutions, the Idaho National Engineering and Environmental Laboratory (INEEL) and the Lawrence Berkeley National Laboratory (LBNL) recently launched the Consortium for Research on the Earth's Subsurface (CORES). The multi-disciplinary, multi-agency initiative will advocate strengthened research efforts for problems associated with the earth's subsurface. INEEL Subsurface Science Initiative (SSI) Director Mike Wright first proposed an effort of this kind in "A Call to Action—Advancing the Subsurface Science Research Agenda," *Subsurface Topics*, December 2002.



The CORES mission was defined at the initial meetings this past summer. It is rooted in the participants' belief that increased investments in geoscience research are required to avert future environmental crises. The mission is:

- Protect the world's aquifers from natural and anthropogenic contamination
- Ensure safe, long-term containment of hazardous materials in the subsurface, the final destination of virtually all of mankind's waste
- Support high levels of agricultural productivity that exclude practices with negative environmental consequences

(Consortium continued on page 2)

(Consortium continued from page 1)

- Improve the identification, characterization and use of energy and mineral resources, and
- Mitigate global climate change through subsurface processes (such as carbon sequestration and vadose zone water cycling).

To achieve CORES' mission—ensuring the sustainability of human life on earth—the participants agreed there must be a coordinated, sustained and sufficiently funded research effort to understand and manipulate subsurface properties and processes. It will not be enough to merely accept the incremental progress being made at today's research funding levels.

Consortium for Research on the Earth's Subsurface (CORES)

http://www.inel.gov/cores/

CORES is sponsoring a series of national workshops to better define subsurface and geoscience research needs. Four workshops are planned for 2004, though topics and dates have not been finalized.

To date, two national workshops have been held. The first, *Coupled Processes,* was held in Berkeley, Calif., on July 30-31, 2003. Information about the meeting is available at http://esd/lbl.gov/coupled_processes_meeting.

The second national workshop, *Challenges in Subsurface Characterization, Imaging, and Monitoring,* was held in Salt Lake City, Utah, on Sept. 24-26, 2003. Information about the meeting is available at http://www.inel.gov/earthscienceconf/.

Contact Donna Guillen, INEEL SSI, at (208) 526-1744 or lh5@inel.gov for information about upcoming workshops.

The pace of multidisciplinary research must be accelerated substantially beyond the status quo with an effort made to integrate the individual pieces of research performed at various institutions.

So far, participants in CORES have identified four general research challenges that need to be overcome. These challenges result from the enormous range of scales involved in conducting subsurface research and the multidisciplinary nature of the research. They are:

- Limited understanding of subsurface properties, processes and parameters, and the coupling among processes
- Inadequate technology for sensing and imaging subsurface properties and heterogeneities, and subsurface chemical, microbiological and hydrological processes
- Lack of comprehensive data sets for conceptual and numerical model calibration and validation, and
- Incomplete understanding of how to apply laboratory data to field-scale problems.

CORES plans to begin tackling these challenges by advocating a dramatically strengthened national research program in the subsurface sciences. Their goal is to improve current standards, methods, models and techniques for gathering and interpreting subsurface data.

To accomplish this, current CORES objectives are:

- Develop a research agenda and interagency proposal for an integrated, multidisciplinary research program to:
  - Vastly improve understanding of the properties and processes in the earth's subsurface
  - Develop new sensors and instruments for characterizing, mapping and visualizing the earth's subsurface in unprecedented detail
  - Apply the new knowledge and tools for solving problems critical to a sustainable society.
- Develop scientific justification and political support needed to ensure adequate research program funding through increased budgets in DOE, the National Science Foundation and other federal agencies.

Recently, DOE Idaho Chief Scientist Linda McCoy stressed the critical need for subsurface science while speaking to researchers and students at the recent INEEL/INRA Subsurface Science Symposium. While she also acknowledged that DOE's sponsorship may be unclear (see *INEEL Expected to Change Focus in 2005*

(Consortium continued on page 3)

The Consortium for Research on the Earth's Subsurface (CORES) held its initial meetings this past summer. The participants' first action was to define the mission, which is rooted in the need for increased investments in geoscience research. CORES is currently sponsoring a series of workshops to define subsurface and geoscience research needs.

INEEL Expected to Change Focus in 2005

In April 2003, U.S. Secretary of Energy Spencer Abraham announced DOE's plan to separate the current contract to run the INEEL into two contracts: one to manage the Laboratory complex, the other to manage environmental cleanup. When new contractors begin operating the complex, presently scheduled for early 2005, the Laboratory will be renamed the Idaho National Laboratory.

One of DOE's goals with this plan is to revitalize the Laboratory's nuclear energy mission so it can respond to the nation's future energy and security requirements. Idaho will be the center of DOE's efforts to develop advanced Generation IV nuclear energy systems, nuclear hydrogen production technology and advanced fuel cycle technologies, as well as to assist the National Aeronautics and Space Administration in the development of space power systems.

> *"…we expect to see the new Lab's subsurface science research efforts broaden beyond environmental issues to include energy and national security challenges."*
>
> *— Dick Jacobsen, INEEL Associate Laboratory Director*

"Our goal, within this decade, is to have this Lab emerge as one of the premier applied research and nuclear engineering institutions in the world, without losing focus on the cleanup work that needs to be completed," said Abraham. "By separately contracting for cleanup under a new contractual framework, the Lab can develop and mature without distraction from other, equally vital, priorities."

DOE also plans for the Laboratory to continue its role as a multiprogram national laboratory. As William Magwood, DOE's director of Nuclear Science and Technology, stated in the INEEL's Strategic Plan, "The INEEL is a valuable multiprogram national laboratory well-positioned to serve our country in the decades ahead."

In describing the INEEL's role as a multipurpose national laboratory, Acting INEEL Laboratory Director Paul Kearns said, "The INEEL will continue to deliver advances that support DOE's missions in energy, defense and science. Our efforts will focus on revitalizing the laboratory and maximizing our R&D capabilities. Ongoing initiatives include Advanced Nuclear Energy Systems, Critical Infrastructure Assurance, Subsurface Science, Hydrogen and Advanced Computing and Collaboration.

"A major thrust will be our ongoing collaboration with other national laboratories, government agencies, academia and private industry. These are pivotal to increasing the value of science and technology for DOE."

One such collaboration is the Consortium for Research on Earth's Subsurface, which was recently launched by the INEEL and Lawrence Berkeley National Laboratory. (See *Sense of Urgency Prompts Creation of Geoscience Research Consortium* on page 1).

"As a multiprogram national laboratory, earth and life science research will always remain core capabilities," said Associate Laboratory Director Dick Jacobsen. "Successful efforts like the Subsurface Science Initiative have earned the lab a great deal of respect among science peers, and we expect to see the new lab's subsurface science research efforts broaden beyond environmental issues to include energy and national security challenges."

A request for proposal to operate the Idaho National Laboratory contract will soon be available. It will be carefully coordinated with the environmental cleanup procurement to ensure environmental work proceeds efficiently and does not interfere with the DOE's research and development interests. More information may be found at http://www.inl-rfp.gov/.

(Consortium continued from page 2)

above), McCoy said, "There is nothing more fundamental than studying the land and water that sustain us. It is crucial for the community that scientists develop a strong voice concerning the need for subsurface and geoscience research."

SSI Director Mike Wright believes that if we are to achieve the breakthroughs that are not easily achievable with slower paced research, it is imperative that current research is enhanced and accelerated. He is soliciting participation in CORES from national laboratories, universities, the private sector and government agencies. "Momentum is building, but much work remains," said Wright. "Please join us in this effort."

Contact: Michael Wright, Ph.D.
(208) 526-3315
wrigpm@inel.gov

Russ Hertzog, Ph.D
Director, INEEL SSI
(208) 526-4092
hertr@inel.gov

Researchers Seek Course to Accelerate Scientific Advancement

For the past few decades, scientists have tried to apply their rapidly growing knowledge of fundamental chemical, biological and physical processes to models that accurately simulate events in complex subsurface environments. Yet despite their tremendous progress, a significant array of fundamental questions remains. Finding answers will likely require a combination of intermediate-scale physical models and coordinated interdisciplinary research. That conclusion was drawn by a number of internationally recognized researchers at a recent workshop hosted by the INEEL.

A group of internationally recognized researchers recently attended a two-day workshop hosted by the INEEL. The participants discussed the types of multi-scale physical experiments needed to significantly advance understanding of coupled physical, chemical and biological processes in porous media. Together, they plan to produce a white paper that will identify the critically needed experiments that currently cannot be conducted. The paper will also make the case for investing in programs and facilities geared toward stimulating interdisciplinary research and accelerating progress in the field of subsurface science.

The INEEL organized the workshop to learn more about the types of multi-scale physical experiments needed to advance the understanding of coupled physical, chemical and biological processes in porous media. They invited researchers from the California Institute of Technology, University of California at Davis, Colorado School of Mines, University of Texas, Oregon State University, Oregon Health & Science University and the University of Alabama. All the researchers have extensive research experience involving coupled processes, modeling and scaling issues.

During the two-day workshop, the researchers identified the areas where scientific advancement has been restricted by the lack of facilities or programs for intermediate-scale research. They explored the idea of consolidating resources and facilities and discussed the other actions that would significantly accelerate scientific productivity.

The researchers concluded that it is vital for the scientific community to have greater ability to conduct experiments using physical models at intermediate length and time scales. Without the ability to observe and understand the scaling of coupled processes in subsurface environments, the advancement of science will be hindered. They also agreed that a coordinated program with centralized facilities would be an extremely valuable national resource.

"Intermediate-scale research requires a critical mass of collaborators, capabilities, facilities and program support, so we will need a coordinated science program."

— George Redden, INEEL geochemist

The researchers plan to jointly prepare and publish their conclusions in a white paper. They will not only describe the types of experiments they believe are critical, they also make a case for investing in programs and facilities geared toward stimulating interdisciplinary research and accelerating progress in the field of subsurface science.

Leveraging National Laboratories

INEEL geochemist George Redden, who hosted the workshop along with INEEL geochemist Carl Palmer, believes part of the solution lies with the national laboratories. According to Redden, national laboratories are in a good position to pool resources and facilities into focused research programs and user facilities, which can then be made available for the scientific community's use. Redden believes this strategy would accelerate interdisciplinary interactions and would stimulate broadened scientific inquiry.

"We not only need facilities, we need to be able to exploit their full potential when we get them," said Redden. "Intermediate-scale research requires a critical mass of collaborators, capabilities, facilities and program support, so we will need a coordinated science program. Not only will the program provide the opportunity for intermediate-scale work, it will distribute the benefits of that work to all participants."

Coordinating Research

When science programs are coordinated, the benefits of research are often amplified. "There are many examples of large-scale research collaborations where scientists work collectively with impressive results," said Redden. "For example, there is the international Ocean Drilling Program, the Hubble Space Telescope and the national Synchrotron Light Sources."

However, researchers rarely initiate the campaign-style research envisioned by the workshop's participants. This is because there are numerous impediments to setting up complex, intermediate-scale experiments with multiple lines of scientific inquiry.

"There is an art to setting up an intermediate-scale experiment," said Eric Roden, a biogeochemist and associate professor at the University of Alabama. "The demand for instrumentation can be overwhelming. But if there were facilities with experienced staff, we could instrument an experiment to answer a more comprehensive set of questions and a major barrier to scientific advancement would be overcome."

Roden envisions a program where research teams representing differing disciplines could independently examine common real-time data sets. "With multiple teams working in the same experimental environment, researchers would likely have far greater data density for any single parameter," said Roden. "They would also have a more comprehensive range of parameters than any single research team could ever consider. A centralized program and facility would offer economies of scale and the ability to coordinate collaborative efforts. The whole would be more than the sum of its parts."

Expanding Facilities

Annette Schafer, an INEEL hydrologist and modeler, described another challenge—the need for facilities that are large enough to allow coupling between processes and that also permit researchers to perturb the system so responses can be measured as functions of length and time. Schafer's view was shared by Jack Istok, a hydrologist and professor of environmental engineering at Oregon State University. Istok has experience in operating intermediate-scale facilities.

"Intermediate-scale experiments provide a level of control over variables and mass balance that cannot be attained in the field," said Istok. "For example, with a larger system with open gas exchange and the ability to vary flow rates, it is possible to observe and understand the complex interactions between multiple types of processes that can't be studied at other scales."

> *"Intermediate-scale experiments provide a level of control over variables and mass balance that cannot be attained in the field."*
>
> *— Jack Istok, Oregon State University hydrologist*

New Approach Will Bring New Knowledge

Workshop participants agreed it is time for research programs and facilities

(Advancement continued on page 6)

Strengthening Interdisciplinary Research

Interdisciplinary research is the modern zeitgeist, but heterogeneities and scaling issues—particularly the physical limits of experimental size and complexity—impose severe limits on interdisciplinary research. If facilities and programs are not designed to overcome the spatial and temporal restrictions of a typical laboratory, the potential for scientific innovation is severely stifled.

"Twenty years ago, it was nearly heretical to work with a colleague outside your specialty, but the questions of a single discipline were readily answerable at typical laboratory scales," said Redden. "Now, working with colleagues from other disciplines is the norm, but unfortunately, the old paradigm hasn't changed when it comes to facilities."n Redden's opinion, the current state of subsurface science is similar to where the sciences of astronomy and oceanography were several decades ago.

"The Hubble telescope and deep submersible Alvin provided profound new insights into the nature of space and the earth, but subsurface science does not possess equivalent means for observing near-surface environments," said Redden.

"Subsurface scientists are much more reliant on inference and drawing analogies to relatively simple conceptual systems. It would be of tremendous value for environmental scientists to have an ability to put various physical, chemical and biological parts together and observe the outcome in complex media."

Variations in Scale are a Key to Breakthroughs

One goal of science is to match theories and concepts with experimental results. The more successfully the two align, the more confident scientists are in their understanding.

Science is also about discovery, which often results when experiments fail when to support current thinking. When experiments cross multiple scales, scientists need to be ready for both success and failure.

"There is nothing like scaling up an experiment to prove your biases and preconceived scientific notions wrong," said Rick Johnson, director of the Center for Groundwater Research at Oregon Health & Science University. "You probably shouldn't quote me on this, but good science strives for failure. We learn the most about the world when our best conceptual models fail to explain our experimental results.

"If you keep your work at one scale, you can get a closer and closer connection between theory and experiment, but it may also become less and less reflective of the reality where coupled processes and heterogeneities dominate," said Johnson. "It may be an artifact of lower scales offering too much control and too little complexity, or perhaps complex systems simply don't exhibit measurable complex behavior at small scales."

To address complexity and interactions, the current tendency is to get a bigger computer rather than add complexity to the experiment. Intermediate-scale research may prove to be a better path, but researchers must be prepared to shift their thinking and be open to both failure and discovery.

"There is no question in my mind that the state of our understanding can rapidly improve through intermediate-scale research," said Tim Ginn, a hydrogeologist and professor of civil and environmental engineering at the University of California at Davis.

Ginn recounted an experience he and other researchers had when they tested their conceptual model for biodegradation in heterogeneous porous media at a one-meter scale. Their initial experiments failed in unexpected ways, but it wasn't due to bad theory or bad technique. Instead, the fundamental scientific 'givens' didn't hold up when they tested conceptual models at an intermediate scale.

"Canonical concepts, which my peers and I accepted as reasonable assumptions based on sound lab-scale science, couldn't account for our results," said Ginn. "These were concepts such as water flow is not affected by minor changes in density, the particular bacteria we used for the biodegradation all remain attached to the porous media surfaces and a particular degradation inhibitor actually worked. Instead, each new experimental observation required us to iteratively rebuild our conceptual and computational models with new underpinnings.

"In the end, we improved our understanding. And we realized the power of pairing detailed modeling with intermediate-scale experimental research as a tool for discovery."

(Advancement continued from page 5)

to evolve. It scientific understanding is to grow more than incrementally, it will require more sophisticated experiments, facilities and approaches.

"The nature of science is to build understanding of simplified systems to construct frameworks, conceptual models and theories of larger and more complex systems," said Larry Lake, a petroleum and geosystems engineering professor at the University of Texas at Austin. "That is what science is about."

Coordinated intermediate-scale physical experiments can accommodate multiple research teams and provide broad collective benefits. According to Tim Ginn, a hydrogeologist and professor of civil and environmental engineering at the University of California at Davis, the value of intermediate-scale research is clear. (See *Variations in Scale A Key to Breakthroughs* above.)

"The common lack of connectivity between scales is a fundamental issue that limits our comprehension of coupled systems in ways we aren't even aware of," said Ginn. "Intermediate-scale research is a new frontier that holds the promise of new knowledge."

Contact: George Redden, Ph.D.
reddgd@inel.gov
(208) 526-0765

Scientific Buried Treasure —
Long-Term Corrosion Study Begins Where Historic Study Left Off

INEEL research engineer and corrosion specialist Kay Adler has a map to a buried treasure—more than a thousand stainless steel specimens buried more than three decades ago. Adler and a team of researchers have begun an effort to recover the specimens, which were left from an early corrosion study that was later abandoned.

Not only will they gain a wealth of scientific data about corrosion rates, their study will increase scientists' understanding of underground material degradation and the behavior of corrosion products in the vadose zone. The data will be invaluable in helping the DOE improve its ability to predict the fate and transport of contaminants.

The original corrosion study, begun in 1970, was conducted by a small team of scientists with the National Bureau of Standards, later renamed the National Institute of Standards and Technology. The team buried 6,324 stainless steel specimens (coupons)—specialty alloys, composite configurations and multiple material forms—at six sites consisting of various soil types throughout the country. The plan was to recover some specimens from each site and examine them at intervals of two, four, eight and 16 years.

However, the project was discontinued after eight years, so the last interval passed without the remaining coupons being exhumed. "Funding was cut, the team disbanded and the work nearly forgotten," said Adler. "There are 190 undisturbed, duplicate specimens per site. The research community is extremely fortunate this work wasn't permanently lost."

When Adler learned the last phase of the experiment had never been completed, she realized there was, in essence, a scientific buried treasure waiting to be recovered. She pulled together an interdisciplinary research team, consisting of scientists from the INEEL, the Savannah River Site, and the original study team, and prepared a research proposal to finish the job.

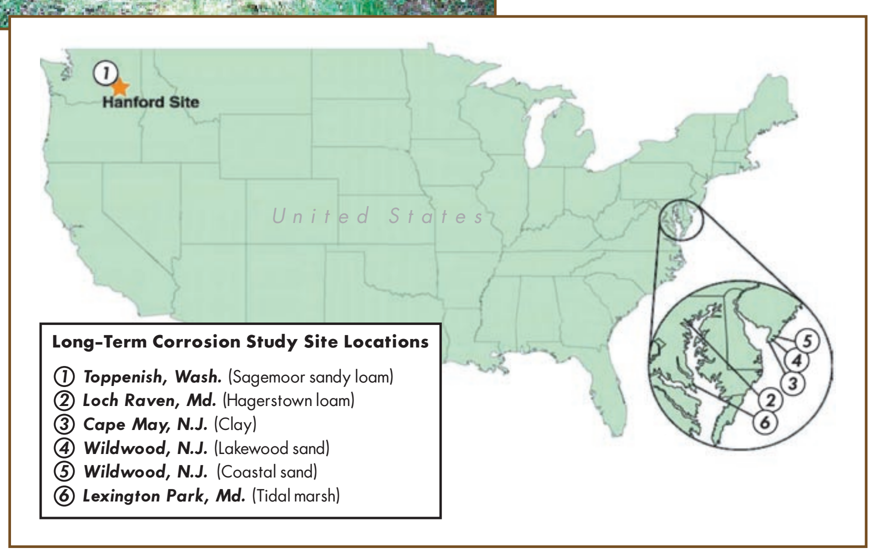
Adler and her team plan to recover the coupons, then correlate the complicated interrelationships between metal integrity, corrosion rates and mechanisms, soil properties and microbiology, plant and animal interaction with corrosion products, and fate and transport of metallic ions. (See *Changing Interests and Passing Time Affect Long-term Studies* on page 8.)

Beginning the Hunt

The team began its study of underground corrosion after a 32-year

(Corrosion continued on page 8

More than three decades ago, the National Bureau of Standards began a multi-year underground corrosion study. The researchers planned to study a variety of stainless steel coupons, which they buried at sites with various soil types across the United States. Before the study was completed, however, it was abandoned, leaving some of the specimens still buried. An INEEL-led research team has begun the effort to recover and study the remaining coupons (locations indicated on the map below. Though some of the original data has been lost, many of the original markers remain. Some of the original markers at the Loch Raven site in Maryland are shown in the photo (left).



(Corrosion continued from page 7)

period by making an effort to obtain any surviving historical background and data from the original study. With the assistance of Edward Escalante, a retired metallurgist and one of the original corrosion test investigators, they began contacting people at each of the six sites.

It wasn't long before they learned that some of the original data (such as the original mass and sizes with corresponding identification) was lost. Even more importantly, they also learned that the environmental conditions at several of the remaining sites had changed dramatically.

As a result of changes in local conditions, one site that was originally located in coastal sand is now buried under coastal dunes. Another site that was located in clay soil changed when surface water was redirected into the area. And a tidal marsh site near the Chesapeake Bay may have been impacted or even lost by dredging activities.

Regional or global changes also have had a broad impact. Three decades of acid rain have affected sites in the Eastern United States, and a layer of volcanic ash from the 1980s Mount St. Helens' eruption was deposited over the site in the Western United States.

"Long-term stewardship has the daunting task of building a foundation of information for future generations," said Adler. "This corrosion study is a poster

Changing Interests and Passing Time Affect Long-term Studies

Inevitably, over the passage of time accompanying a long-term study, scientific and social interest in the potential results changes. The INEEL's new corrosion study project offers an example of these types of changes.

When the original National Bureau of Standards corrosion study project was designed more than thirty years ago, the three members of the original research team, all specialists in the study of corrosion, were primarily interested in how the environment corrodes metals.

Since then, the culture of science has changed dramatically. Science has shifted from a single-discipline focus to multidisciplinary research accompanied by increased social concerns about the environment. The questions posed in the original corrosion study are still of interest, but new questions about the effect of corroding metals on the environment are of equal or greater interest.

"We do science differently now," said Kay Adler, an INEEL research engineer who is the principal investigator of the new corrosion study project. "Our team is able to learn as much, or more, about environmental response as about corrosion of materials. In fact, we expect to examine topics ranging from soil physics and chemistry to microbiology and metal ion transport."

Adler said such changes in interest are typical for the long-term corrosion research in which she has been involved. As an example, she described a study she initiated in the mid-1990s that involved a variety of low-level waste forms and materials, including beryllium.

"When we initiated the study, we had already been burying low-level waste for decades, but we thought it was of scientific interest to better understand how the materials break down," said Adler. "Beryllium was just one of many materials we included, even though at the time it was considered of little particular interest or concern. When the time came time to dig up the first round of materials, things had changed. There was a significant interest in what happened to the beryllium."

Since the original long-term corrosion study began more than thirty years ago, its scientific value has increased. Today, researchers not only have more answers, they have the understanding to ask new questions.

When INEEL scientists buried beryllium samples while conducting a research study in the 1990s, beryllium was considered just another low-level waste form component. Three years later, when the samples were recovered, beryllium was listed by the U.S. Environmental Protection Agency (EPA) as one of 129 priority pollutants, and considered to be one of 14 most noxious heavy metals. Not only did the passage of time affect the buried coupons, shown before (near right) and after (far right) cleaning, it also affects research priorities and concerns. Today, we are more aware of the potential long-term environmental impact and appropriate disposal of irradiated metals, including beryllium.

child for long-term stewardship. It allows us to examine how each of the six sites has changed in character over the study period. We will gain information that is useful now and in the future and the study will demonstrate how valuable long-term studies can be to future generations."

The team has already begun facing its first challenge—gaining access to the sites where the specimens are buried. This has been challenging, particularly because the original managers of each of the sites have changed, in some cases many times.

"Departments and agencies change over time, so our first challenge was identifying the organizations and individuals who had authority over the sites so we could begin a dialogue through that organization's hierarchy," said Adler.

In most cases, the people they contacted were unaware of the study sites or knew very little other than the location of markers. Eventually, however, the team located the new land managers and began discussions about gaining access to recover the specimens and take associated environmental samples. Negotiations at most of the sites are still underway and generally involve establishing simple intragovernmental agreements with other federal agencies.

However, one site in Toppenish, Wash., has required more complex negotiations. The site, originally accessed by a utility right-of-way, is now part of the Yakama Indian Nation. It is of particular interest to DOE because its arid soil conditions are similar to those at Hanford and the INEEL. Government-to-government negotiations with the Yakama Nation are already under way, but it may take time to work out details acceptable to the tribes.

Adler, who is trying to be patient, says the detective work and negotiations aren't as interesting or exciting as the research. "We had hoped to open the first site this fall, on the 32nd anniversary of when the coupons were placed," said Adler. "Now it looks as though we will have to wait until access agreements are established. With luck, however, we will have our opportunity to recover the coupons as early as March 2004."

When the team is finally able to retrieve the coupons and take samples, it expects to depart from the original experimental design. Adler believes that with three decades of advances in science and technology, it would be unwise to follow the original methodology.

"Applying new techniques and technologies is one of the great rewards, and one of the challenges, of long-term, multiphase research," said Adler. "The trick is knowing when to stick to the original design and when to depart. It's important to be true to the original experiment, but you must also be flexible and update and augment your approach to take advantage of changes in science."

Because of the advancements of the past three decades, scientific analysis techniques that were unavailable to the original researchers will be used to study the metal ions released through corrosion into the surrounding soil and environment. Techniques—such as reflectance infrared and Raman spectroscopy, secondary ion mass spectrometry, imaging laser desorption/ionization Fourier transform mass spectrometry and vertical scanning interferometry—will help correlate measured corrosion rates with corrosion products and microbes, as well as assess surface profiling and pit depths. Adler expects these analysis techniques will help scientists learn a significant amount about how specialized microbes contribute to the complicated process of corrosion and metal mobility in soils.

"Scientists of thirty years ago would not even have known to ask the questions that we currently have the ability to study," said Adler. "When the study began, microbial-influenced corrosion was starting to be recognized. But no one would have thought you might be able to sequence the DNA of microbes in the soils to see if exposure to metals triggered a specific gene. It would have been unfathomable to a biologist, much less a corrosion engineer."

Weighing Decision for Future Study

While negotiations with the various land managers proceed, the team has been considering whether to finish the experiment or allow it to continue into the future.

For statistical reasons, the original test involved placing duplicate samples in separate locations with identical burial treatments. Now, because of the missed interval at the 16-year mark, two sets of samples remain buried. Adler says there are good statistical reasons to take both sets of the last remaining samples.

However, the team is considering another idea—taking only one set of samples and leaving the remaining sample for another generation.

"We are the beneficiary of an earlier effort, but the study may not need to end with us," said Adler. "A common practice in archaeology is to leave portions of archaeological sites undisturbed for future researchers, who will have the benefit of more advanced techniques and understanding. Evaluating the trade-off of greater statistical certainty today against the technologies and questions of tomorrow is difficult, but intriguing."

Contact: Kay Adler Flitton
mka@inel.gov
(208) 526-0525

Note: This research is funded by DOE's Environmental Management Science Program (EMSP) and conducted by Kay Adler Flitton in collaboration with C. Bishop, G. Groenwold, Ph.D., M. Leecaster, Ph.D., P. Nagata, R. Rogers, Ph.D., J. Scott, Ph.D., and L. Zirker (all of the INEEL); M. Louthan, Ph.D. and K. Marshall (of Savannah River); and E. Escalante.

INRA/INEEL 2003 Subsurface Science Symposium

For four days in October, more than 200 researchers, professors, and students converged at the Salt Palace Convention Center in Salt Lake City, Utah, to attend the 3rd Annual Inland Northwest Research Alliance (INRA) Subsurface Science Symposium. The theme was Advances in Understanding and Modeling Subsurface Processes.

The symposium offered an array of presentations, discussions and student poster sessions, which spanned the various disciplines associated with subsurface science, including environmental policy and management, geophysics, bioremediation, technology transfer, hydrology, geochemistry and modeling.

"Modeling subsurface processes is a great topic for this symposium because it is one of the steps that provides a strong link across disciplines," said Mike Wright, the director of the INEEL's Subsurface Science Initiative. "Students who want to conduct research on subsurface processes not only need an understanding of modeling techniques, they also need an understanding of the multidisciplinary nature of this field. I think the breadth of sessions and topics provided both students and researchers a chance to connect in ways that will further the field of subsurface science."

Connecting student and national laboratory researchers is part of INRA's mission as a partner in the management of the INEEL. "So far, INRA has sponsored 28 funded projects, which have produced 41 peer-reviewed publications," said INRA Executive Director Gautam Pillay. "Collaborative research proposals between INEEL staff and university faculty have directly resulted from interactions at each of these annual symposia and we fully expect the same for this year. Because of the personal interactions among attendees, this symposium is a valuable opportunity for networking and for learning about ongoing research at each of the INRA institutions and the INEEL."

INRA, a partner with Bechtel BWXT Idaho in the management and operation of the INEEL, is a nonprofit scientific and educational organization consisting of eight Western research universities. INRA was formed to train future experts in fields of importance to the INEEL and the region, and to develop important collaborative research initiatives.

In FY 2001, the total research and development budget for the INRA universities—Boise State, Idaho State, Montana State, Utah State and Washington State universities, and the universities of Alaska at Fairbanks, Idaho and Montana—was approximately $530 million. Collectively, in terms of research funding, they rank as the seventh largest institution of higher education in the country.

More information about INRA is available at http://www.INRA.org

INRA Executive Director Gautam Pillay (right) hosted the 3rd Annual INRA/INEEL Subsurface Science Symposium, which was held recently in Salt Lake City, Utah. More than 200 researchers, professors and students attended sessions that focused on modeling subsurface processes and spanned various disciplines.

Highlights of the Symposium's Opening Sessions

True to the diverse nature of subsurface science, the three keynote and plenary speakers addressed topics ranging from the moon to microbes. The keynote speaker was Dr. Harrison 'Jack' Schmitt, a geologist, Apollo 17 astronaut and former New Mexico senator. Not only was Schmitt the last man to ever walk on the moon, he was also the first and only scientist to do so.

Schmitt presented an entertaining and insightful account and video of his lunar experience, a three-day visit in December 1972. His commentary, on conducting scientific experiments, collecting rock and soil samples, and driving the lunar rover to nearby mountains, was peppered with technical details on lunar geology.

Schmitt closed with his thoughts on the prospects for future space missions, including human exploration of Mars. According to Schmitt, "If a helium-3 lunar initiative began by 2005 with assured funding, the first human mission to Mars could be launched by 2015."

Biologist Terry Hazen of Lawrence Berkeley National Laboratory focused on how microbes can be used for environmental remediation, focusing on critical biogeochemical treatment trains for breaking down organic contaminants.

Hazen, an expert in natural attenuation and bioremediation, described the widespread nature of environmental contamination. He pointed out that 73 million people live within four miles of a Superfund site, then also noted that 60 percent of earth's biomass consists of microbial life, which is often well-suited to breaking down much of this environmental contamination.

Hazen emphasized the comparative advantages of bioremediation over other traditional approaches. However, he stressed there were gaps in knowledge and areas where critical research is needed in order to translate this research into practical field applications of in situ bioremediation.

In an instructive overview of near-surface geophysical imaging, Stanford University geophysicist Rosemary Knight focused on the environmental applications of geophysics to elucidate subsurface structure, content and processes. She placed particular emphasis on the value of a bridging discipline that is known to geophysicists as rock physics.

Rock physics provides the necessary calibrating step that allows geophysicists to convert geophysical measurements of properties, such as the velocities of acoustic waves or measurements of electrical resistivity, into information about the material properties and processes in the subsurface, such as permeability, porosity or the movement of water and contaminants.

According to Knight, rock physics of properties relevant to oil exploration and production are well studied, but rock physics relevant to environmental problems is lagging behind. To improve the application of geophysical measurements to environmental problems, Knight believes environmental geophysicists must enhance the utility of the rock physics to environmental applications.

The 2003 INRA/INEEL Subsurface Science Symposium featured three keynote and plenary speakers. The first, Dr. Harrison "Jack" Schmitt (top), spoke of his experience as both the first scientist and last astronaut to walk on the moon. Biologist Terry Hazen (middle), of Lawrence Berkeley National Laboratory, spoke about the importance of using biogeochemical treatment trains for breaking down organic contaminants. Geophysicist Rosemary Knight (bottom), of Stanford University, spoke of the need for environmental geophysicists to enhance the utility of rock physics as a bridging discipline.

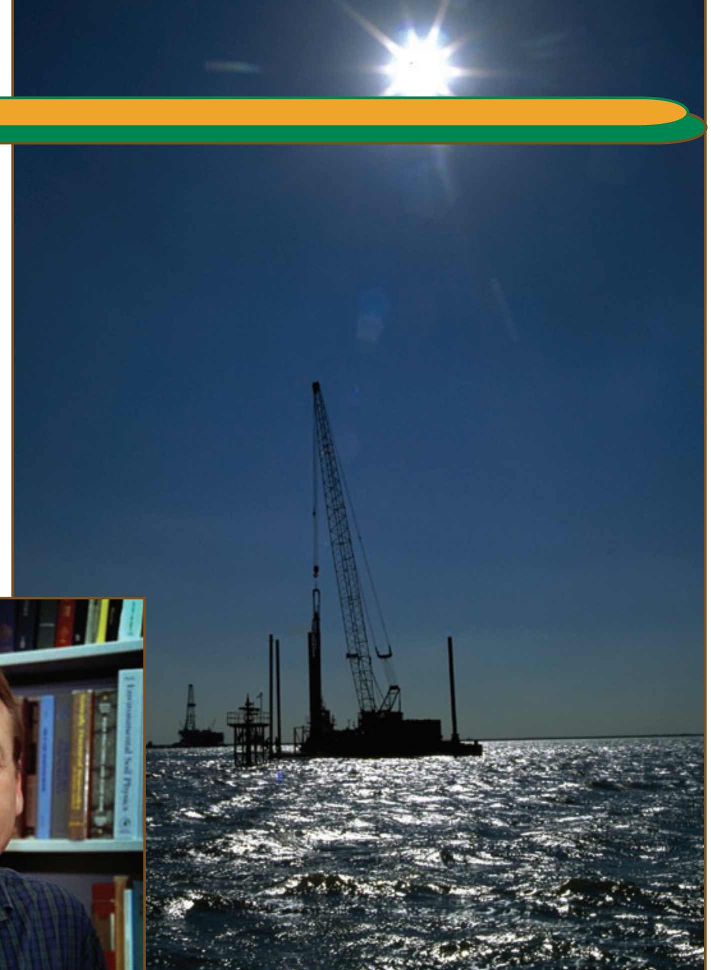
Detecting Overpressured Zones has Potential for Huge Benefits

Most of the Gulf of Mexico's oil reserves are found within 200 meters of overpressured zones, regions that routinely present engineering difficulties and safety risks. INEEL and industry researchers have a radical explanation for the formation of pressure seals in many of these zones—the 'vapor lock' theory. Bolstered with this new understanding, the researchers believe that overpressured zones may potentially be a major unrecognized source of oil and gas reserves and they are working on new methods to detect them.

"This line of research has the potential to significantly reduce the costs of exploration and drilling," said INEEL petroleum engineer Mike Shook, who is leading the team of researchers. "Not only will this understanding improve drilling safety and efficiency, the risks of formation damage and blowouts will be reduced."

The new understanding of pressure seals began with geophysicist William Benzing. More than a decade ago, Benzing's research produced the 'vapor lock' theory of basin evolution. At the time, Benzing was supporting Conoco's oil exploration efforts by conducting research on the acoustic properties of gas-filled sands.

Gas reflects sound in a variety of characteristic ways. But frequently, seismic profiles show false bright spots where acoustic velocities look like a gas-filled sediment, but really are just a geophysical 'mirage.' Benzing was curious why seismic techniques for identifying gas in subsurface formations sometimes indicated gas deposits where there were none.



Some of the most productive oil and gas reserves in the Gulf of Mexico (offshore construction shown in photo above) are associated with overpressured zones. A team of INEEL and industry researchers, including INEEL petroleum engineer Mike Shook (above), have developed the 'vapor lock' theory as one explanation for these zones. The research currently underway promises both better methods for detecting these pressure gradients and strong evidence of vast unexploited oil reserves.

Benzing designed an experiment by which he hoped to improve seismic techniques for discriminating real gas reservoirs from mirages. To form gas-rich sediment in a geologic matrix, he laced fine silt with yeast and deposited it into a column of sugar water. His expectation was that, over time, this would produce a uniform buildup of gas in the pore spaces of the material. This uniform system would allow him to interrogate it acoustically over different frequencies so as to better understand the acoustic properties of gas in porous media.

But Benzing's experiment didn't play out as expected. As gas reached saturation level in the liquid, it exsolved into the pore spaces and pressure began to build in the system. The pressure, however, was not uniformly distributed. Instead, it formed a pressure seal where the gas exsolved. The presence of free gas reduced the permeability in the column, just like a lithologic barrier would. Capillary tubes placed along the column showed a vertical pressure gradient profile identical to a lithological permeability seal.

In 1992, Shook's manager gave him a videotape of Benzing's experiment. "I never had a chance to watch it until one Friday when I had 15 minutes to kill before meeting some friends after work," Shook said. "I popped in the video and was blown away."

To discern what was going on, Shook said he grabbed a marker and wrote some equations related to flow in porous media. "Bill's experiment was so elegant that it was simple to explain mathematically," said Shook. An hour later, though late meeting friends for happy hour, he had identified a causal relationship for the pressure buildup and the vapor lock phenomena.

According to Shook, for a dynamic system, with pressure governed by Darcy's Law, the pressure gradient is inversely proportional to effective permeability. As gas is generated within the system, it exsolves and displaces the water from the pores. The presence of a free gas phase reduces the effective permeability to water, and thus, through Darcy's Law, forms a pressure seal.

"The pore pressure can occasionally overcome the hydrostatic pressure," said Shook. "That can cause ruptures in the vapor seal, but it quickly reforms and acts in many ways like a lithological seal, trapping gas and fluids beneath it."

Subsurface Pressure Gradients

In an open (unconfined) system, pore pressure is the same as the hydrostatic pressure. Pore pressure refers to that portion of the overburden pressure that is not supported by the rock matrix, but instead is supported by the fluids or gases in the pore spaces.

Closed (confined) systems occur when the communication is interrupted between surface fluids and fluids at depth, and the fluids become entrapped within the formation. In this type of system, the pore pressure can become overpressured due to a lithological pressure seal, such as a low-permeability shale layer confining a more permeable formation below.

Now, evidence is mounting that pressure seals are commonly formed by 'vapor lock,' when exsolved gases in a dynamic system block the pore spaces.

New Understanding of Basin Evolution

After that revelation, Shook and Benzing began working together to understand how the vapor lock model might explain the potential sealing and trapping of hydrocarbon reservoirs in the Gulf of Mexico. They used a computer-based equation-of-state model that combined modern computer modeling with work on the properties of gas solubility identified in the 1950s. Eventually, they were able to extend the model to more realistic basin conditions.

Their numerical simulations (first published in forums and journals, such as *Oil and Gas Journal* and *Offshore* in the late 1990s) showed that under subsurface conditions, gas solubilities exhibit minima (where gas comes out of solution) at specific temperatures. Therefore, in a geologic setting, vapor lock pressure seals should form along these characteristic isotherms, as shown in the illustration at right.

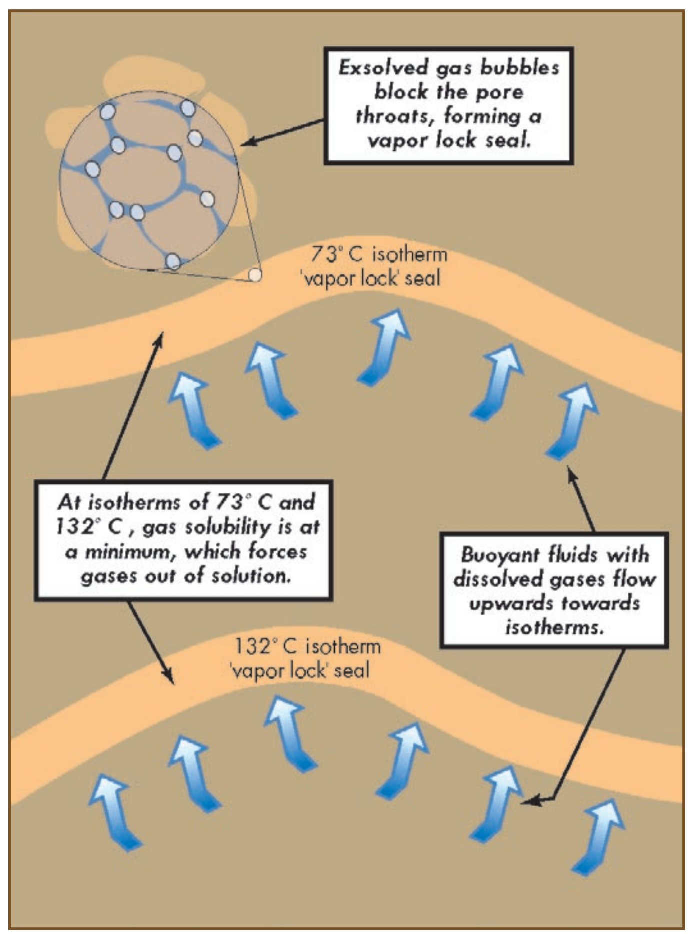
They also discovered that while different gas compositions result in different isotherm temperatures, the system is always bimodal, having two characteristic solubility minima. For example, using a gas mixture of 75 percent methane and 25 percent carbon dioxide, the first vapor lock pressure seal would develop along an isotherm corresponding to 73° C. This isotherm corresponds to well-known pressurized gas plays in the Gulf of Mexico.

The second pressure seal predicted by the theory and modeling would then develop along an isotherm corresponding to 132° C. Until recently, this second isotherm was not associated with hydrocarbon fields; however, Shook believes it's an oversight that needs to be reevaluated. (See *Second Horizon May Be Rich Source* below.)

According to Shook, the team's research shows a relationship between

Overpressured continued on page 14)

The illustration (below) shows the conceptual dynamics of a system containing a mixture of 75 percent methane and 25 percent carbon dioxide, which would form two vapor lock seals at isotherms of 73° C and 132° C. The 73° C isotherm corresponds to well-known pressurized gas plays in the Gulf of Mexico and might explain the potential sealing and trapping of hydrocarbon reservoirs in the Gulf of Mexico.



Overpressured continued from page 13)

the locations of the pressure seals and hydrocarbon accumulation. When sands in the zone of gas exsolution become charged with hydrocarbons, the interplay of the pressure zone with local lithology and thermal anomalies creates structures that can trap oil and gas in a variety of novel ways.

The team's theory, that vapor lock is a mechanism for creating overpressured zones related to hydrocarbon development, is slowly gaining credibility in the scientific community as evidence mounts in its support. But Shook said the experience has led him to believe that paradigms fall hard and slow, describing a presentation he gave at an American Association of Petroleum Geologists meeting.

"When I presented a paper on vapor lock as a mechanism for overpressured zones related to hydrocarbon development, I was confronted like I was a heretic," said Shook. "Lithological seals

Second Horizon May Be Rich Source

If scientists are correct, there is still a virtually untapped source of oil and gas in the Gulf of Mexico region that may be right under drillers' noses. INEEL petroleum engineer Mike Shook thinks it may be in a second horizon lying in shallower (<20,000 feet) near-land systems, some of which are beneath existing fields. If he's right, the amount of gas in the second horizon could be equivalent to the total gas produced by the region to date.

Overpressured zones, the source of much of the Gulf of Mexico's oil and gas production, are currently identified using theoretical and modeling work that predicts pressure seals and oil deposits corresponding to a 72° C isotherm. The vapor lock theory offers an explanation for this relationship. At that temperature, gases are at the solubility minimum (least able to stay dissolved in solution). Free gas, which has come out of solution, displaces liquid in the pore spaces, forming a pressure seal that is capable of trapping hydrocarbons.

The vapor lock theory and supporting models also predict a second isotherm. This second isotherm, at 132° C, is not understood as correlating with existing plays and tends to remain hidden in relatively unexplored strata. "If we're right, there are significant oil and gas fields to be found in shallow coastal areas at or near the 132° C isotherm," said Shook. "What's more, there are many more structures that hold reserves, structures that geologists haven't previously looked for."

According to Shook, the interplay of these overpressured zones with thermal gradients and lithology creates a number of counter-intuitive structures that likely have reserves. "Places where pressure seals have burped, like we have seen in the lab, could fill sands in places you wouldn't expect," said Shook. "The interaction where a pressure gradient in shale crosses into sand can create lateral movement and trapping where most geologists wouldn't look for it."

Shook began looking for corroborative evidence of a discovery in the second isotherm horizon and almost immediately found one in the Galveston region of the Gulf of Mexico. He shakes his head when he recalls it.

"At the same time I was busy theoretically predicting a field should be there, someone discovered it right in my old backyard," said Shook, who grew up near Galveston.

In May 1997, a well drilled by the exploration company TransTexas Gas Corporation hit a 16,000 psi pore pressure structure at 15,400 feet, 400 feet higher than predicted and resulting in a temporary blowout. The discovery turned out to be a large new natural gas and condensate field, estimated to potentially exceed one trillion cubic feet of natural gas equivalent according to company press releases.

In Shook's eyes, the most important thing was that this strike in slightly deeper strata may correspond to the second isotherm. "I don't have access to the temperature data for the well," said Shook. "But the find is at the right depth for the second isotherm."

After learning about the discovery in *Oil and Gas Journal*, Shook was also able to explain to the engineers at TransTexas why their predictions were off. "Based on our studies of the acoustic signature of overpressured zones, we know those zones have lower acoustic velocities at the boundary formed by the pressure gradient seal," said Shook. "The engineers interpreted the depth to formation based on standard velocities when they were actually slower at the pressure gradient. They were lucky. The pore pressure they encountered was actually more than what is considered normal for overburden. Hitting that kind of pressure 400 feet early is pretty dangerous."

are comfortable to conceptualize, they are static and have physical properties that show up in well logs and core samples. By contrast, vapor lock pressure seals are mercurial. They can move and change but if you understand the math, they are as real as holding a core sample. Benzing has been fighting this battle for more than 15 years, but I think we are finally making headway."

The Case for Pressure Gradient Detection — *Blowout at Brazos #417*

Overpressured zones in the Gulf of Mexico's rich oil reserves are known for risk nearly as well as they are known for oil. They account for only 10 percent of the hydrocarbon reservoirs, but nearly 50 percent of the hydrocarbon production. They also account for numerous blowouts and accidents, some of which have had disastrous human and economic consequences.

One blowout occurred in July 2001 at Brazos #417, about 26 miles south of Freeport, Texas. The crew was drilling into a known deposit of natural gas. At 4:15 a.m., they broke into it—13 or so feet before expected. From 7,667 feet below the surface, a geyser of explosive gas and hot mud began erupting out the 20-inch pipe with a roar described by one worker as similar to a 747 taking off next to your head. Fortunately, the gas never ignited and the workers, except one, survived the accident and subsequent evacuation. After an effort to directly cap the blowout was abandoned two weeks later, another multimillion dollar drilling operation began—to drill a pressure relief well to plug the blowout.

As exploration and drilling moves into deeper Gulf waters, the investment and level of human and economic risk will increase. Hundreds of workers will be required to man rigs, with installation of a single well costing as much as $50 million. The limits of technology will be stretched in drilling to depths of 20,000 to 30,000 feet. As the human and economic stakes are raised, the toll of blowouts like the one that occurred at Brazos #417 make the ability to detect and quantify overpressured zones increasingly imperative.

Finding the Signature of Overpressure

One area of research offering immediate and abundant benefits is developing and improving the ability to detect and quantitatively evaluate the signature of these elusive structures. Currently, Shook and his team are working on a low-frequency acoustic method capable of detecting geopressure transition zones in vertical seismic profiles. "We have already patented and are focused on an approach that quantitatively measures acoustic phase shifts caused by pressure gradients," said Shook. "Theoretically, we can tell the depth, magnitude and thickness of subsurface pressure gradients."

So far, the team has successfully simulated the approach with computer models. Now they hope to prove the model's validity with geophysical and well data obtained by a collaborator at Unocal Corporation. Eventually, they expect the ability to detect overpressured zones will result in new deployable methods for drilling applications.

"I expect our R&D on vertical seismic profiles and detecting overpressured zones will have immediate payoffs in cost and drilling safety," said Shook. "With prior knowledge of pore pressures and gradients, correct mud densities and appropriate sealing and casing can be selected, and blowouts and formation damage avoided." (See *The Case for Detection: Blowout at Brazos #417* above.)

Though the acoustic signature of a pressure gradient currently does not differentiate between a vapor lock seal versus a lithological seal, Shook expects improved detection of overpressure will begin showing the evidence that supports vapor lock theory. As it does, he expects the industry will realize that the second isotherm could hold huge untapped reserves in the Gulf of Mexico.

"As far as exploration goes, the broader implications of this line of research are less obvious, though more revolutionary. It may take a bit longer to sink in. But if we're right, there could be twice as much oil in the shallow coastal sediments of the Gulf of Mexico as currently thought."

Contact: G. M. (Mike) Shook
ook@inel.gov
(208) 526-6945

Note: This research was funded by the Department of Energy and Fossil Energy Technology Center, and is being conducted by G. M. Shook (of the INEEL); W. M. Benzing, Ph.D. (of RevTek Associates), and Sam Leroy (of EarthView Associates).

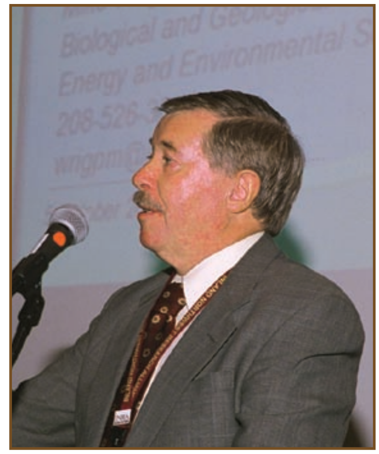
SSI Director Mike Wright to Retire

Mike Wright. director of the Subsurface Science Initiative, has announced his intention to retire right after the first of the New Year. Russ Hertzog, Ph.D., the geophysics discipline lead, has assumed Wright's duties as SSI director. Melinda Hamilton, Ph.D., the biotechnology discipline lead, will serve as acting director for the Biological and Geological Sciences Division.

"It isn't easy for me to leave the INEEL," said Wright. "Because of our stellar scientific and engineering staff, this is a marvelous place to work. But I am past 65 now, and my wife reminds me that it's time to let my work go and move on. After retirement, we intend to do some traveling and pursue a variety of interests."

Before Wright leaves, he plans to work as much as possible on the CORES initiative to help ensure its success. "I believe the time is right for a national subsurface research agenda to be put on the table," said Wright. "I feel very strongly about the importance of the work we are doing through the Subsurface Science Initiative and hope to continue playing a role from outside the Lab to see it succeed."

Contact: Michael Wright, Ph.D.
(208) 526-3315
wrigpm@inel.gov



Mike Wright (shown during a recent address at the 2003 INRA/INEEL Subsurface Science Symposium) plans to retire in January 2004. Russel Hertzog, the geophysics discipline lead, has been named the new director of the SSI.

SUBSURFACE
— SCIENCE —
INITIATIVE

Subsurface Science Initiative
INEEL MS 2214
P.O. Box 1625
Idaho Falls, ID 83415-2214

Address Service Requested

PRESORT STD
U.S. POSTAGE
PAID
IDAHO FALLS, ID
PERMIT NO. 73

http://subsurface.inel.gov